IQPC Conference *“Advances in Rotor Blades for Wind Turbines”*
Bremen, 25.-27.02.2014

Segmentation technology for large onshore blades

Research by NORDEX @ DLR

Lutz Beyland, Composite Design Engineer,

German Aerospace Center (DLR), Institute of Composite Structures and Adaptive Systems
Nordex Energy GmbH, Engineering

Dr. Jochen Birkemeyer, Head of Blade Engineering,

Nordex Energy GmbH, Engineering

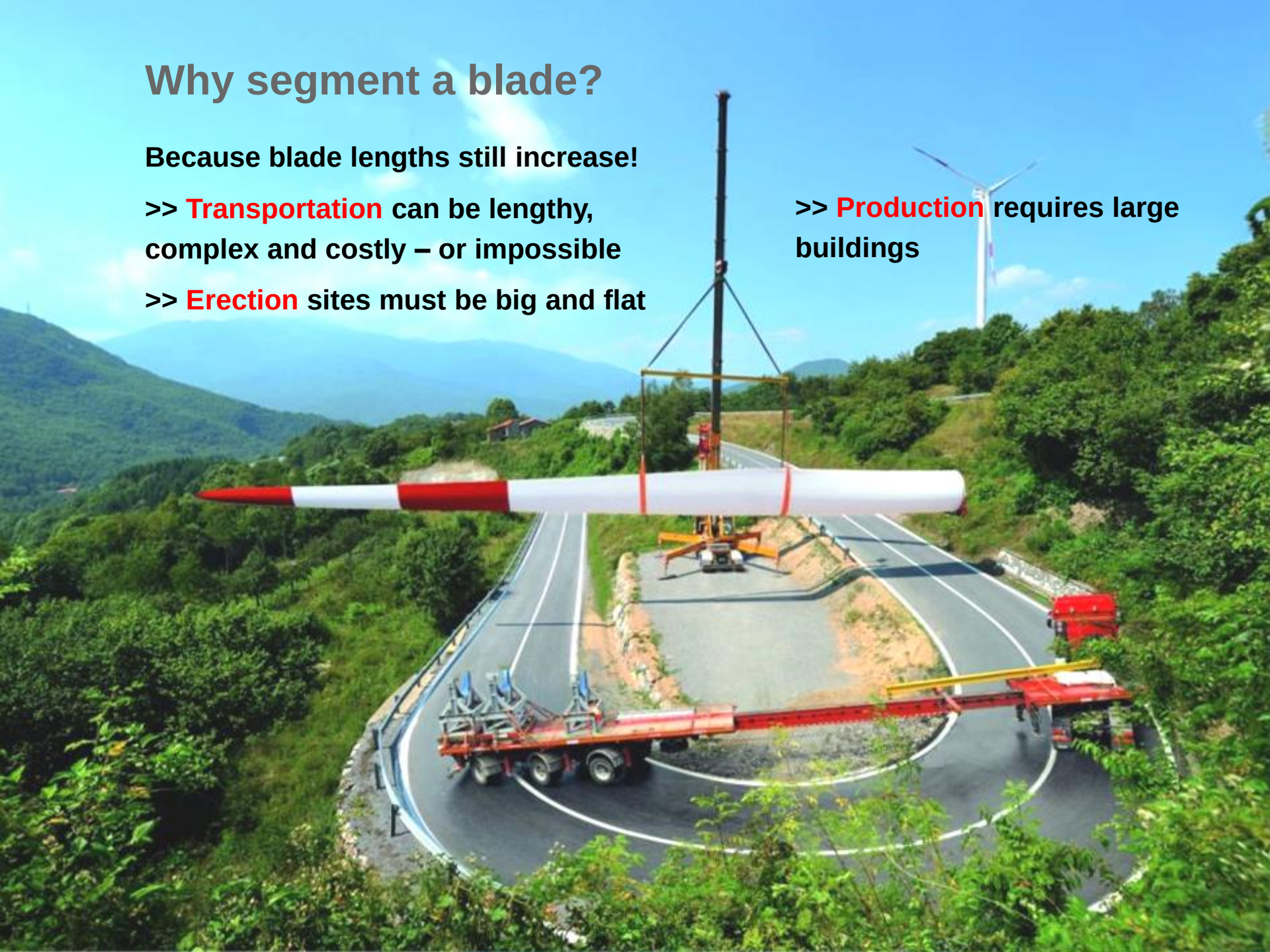
Why segment a blade?

Because blade lengths still increase!

>> Transportation can be lengthy, complex and costly – or impossible

>> Erection sites must be big and flat

>> Production requires large buildings



Outline

1. **Project Overview**
2. **State of the art**
3. **Segmentation position**
4. **Concepts**
5. **Conclusion and outlook**

Sponsorship from Nordex and DLR

Objective:

Investigation and evaluation of joining concepts for segmented rotor blades using the following criteria:

Load bearing capacity, mass, process stability during manufacturing, process stability during assembly on site, quality control and costs.

Action:

1st year

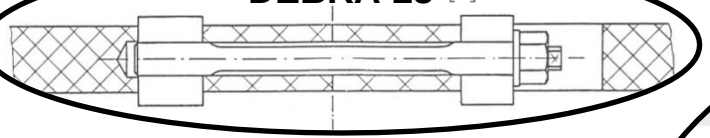
- Literature study
- Generate and evaluate joining concepts
- Choice of preferred concept(s)

2nd and 3rd year

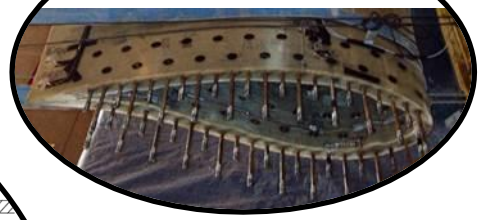
- Detailed design of favored concept
- Verification of structural integrity
- Experimental testing of critical components

Overview of past segmented blade activities

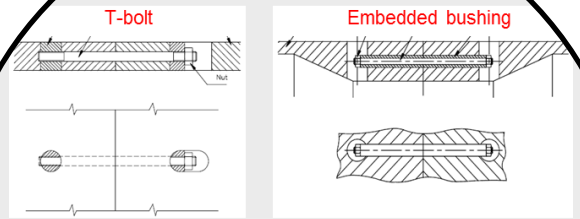
DEBRA-25 [1]

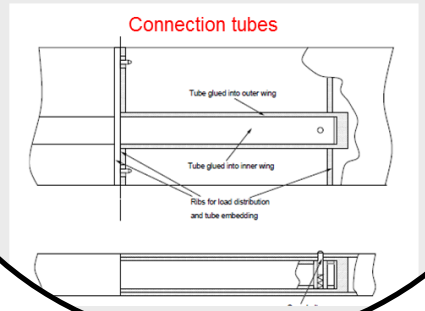


Megawind [3]



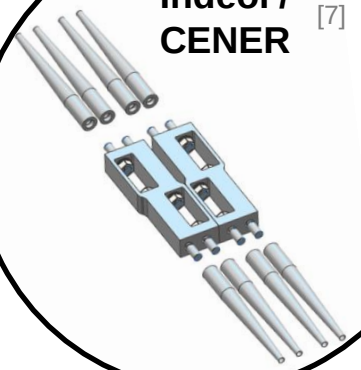
JOULE III [2]



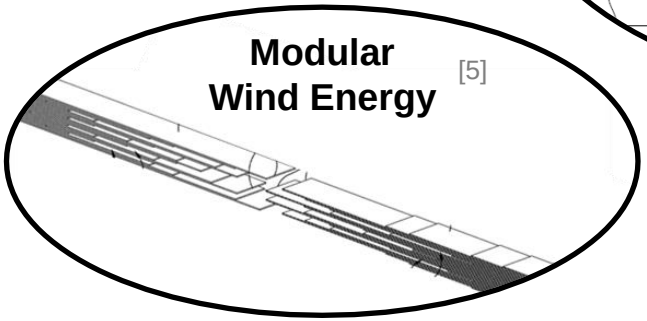


Enercon E126 [4]

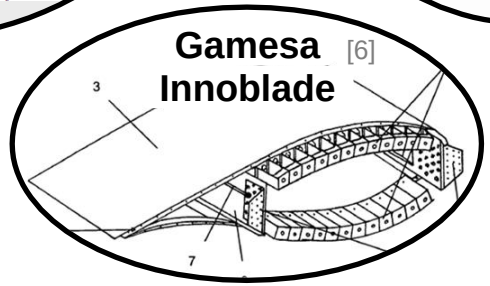
Indeol / CENER [7]



Modular Wind Energy [5]

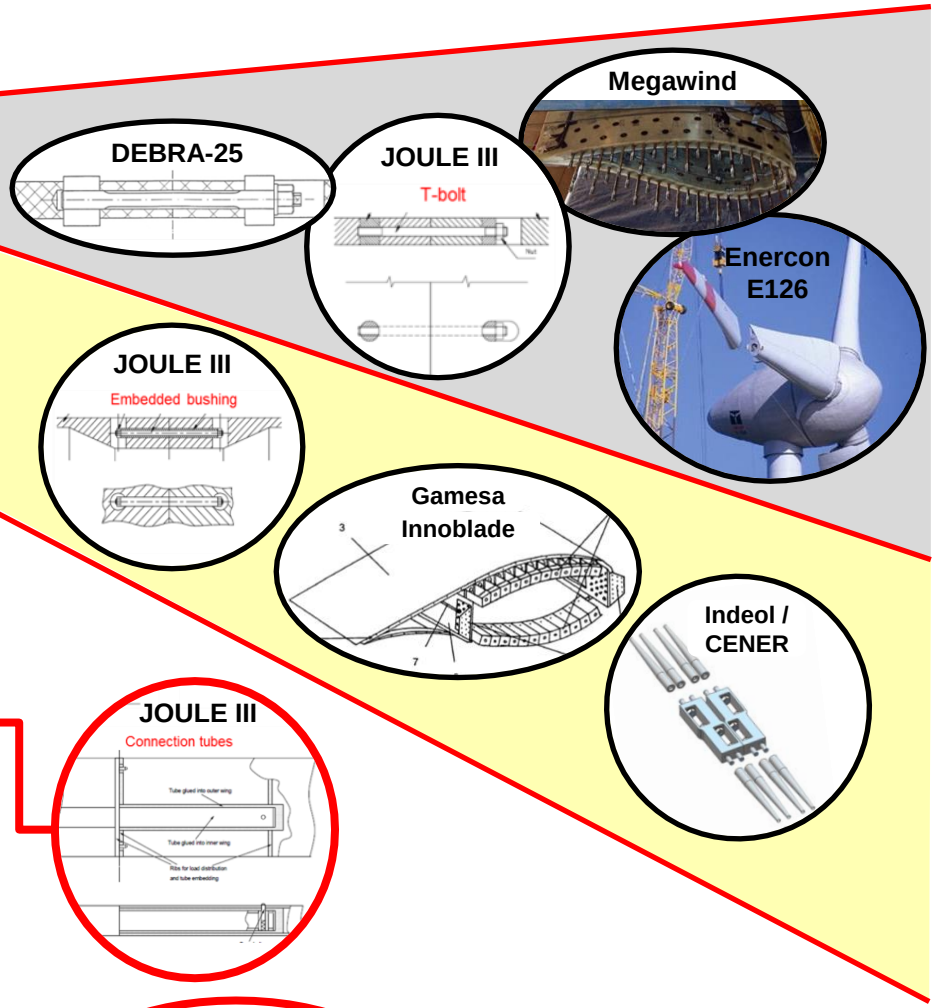


Gamesa Innoblade [6]



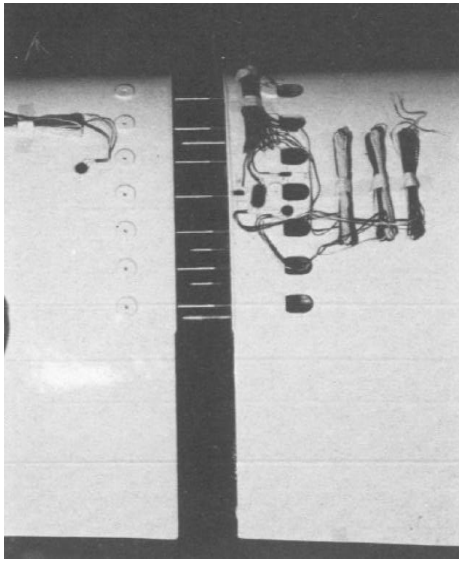
Classification

- Connection principle
  - Detachable
    - Bolting in longitudinal direction
      - T-bolts
      - Metallic inserts
    - Bolting in transversal direction
      - Form-fit
      - Force-fit
    - Bolting of pieces with a large overlap
      - Connection tubes
      - Bolting of shear web
  - Non-Detachable
    - Welding of thermoplasts
      - Single lap
      - Multi lap
    - Bonding of thermosets
      - Single lap
      - Multi lap

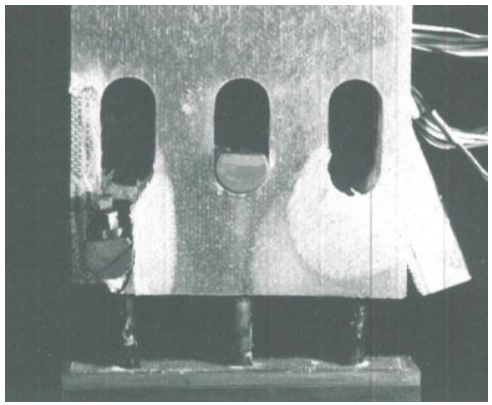


DEBRA-25

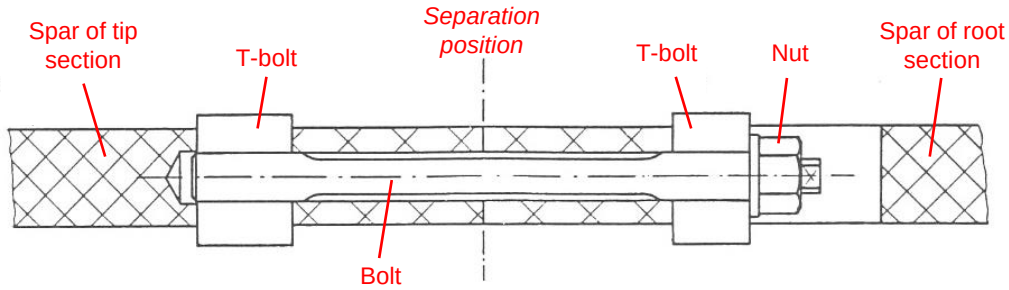
Time span:	1980 – 1991
Company:	DFVLR Stuttgart (today: DLR)
Blade length:	11,6m (ca. 5,8m + 5,8m)



[1]



- Blade structure similar to modern blades
- **T-bolt**-connection of spar caps
- Extensive static und dynamic tests:
  - Coupon level
  - Static und dynamic flapwise blade test
  - Experimental turbine 18 years in service



Result: T-bolt connection proofed technical suitability

JOULE III (1)

Time span:	1997 – 2001
Companies:	LM, DLR, TU Delft, …

Blade length:	23,3m (7,3m + 16m) 13,4m (4,5m + 8,9m)

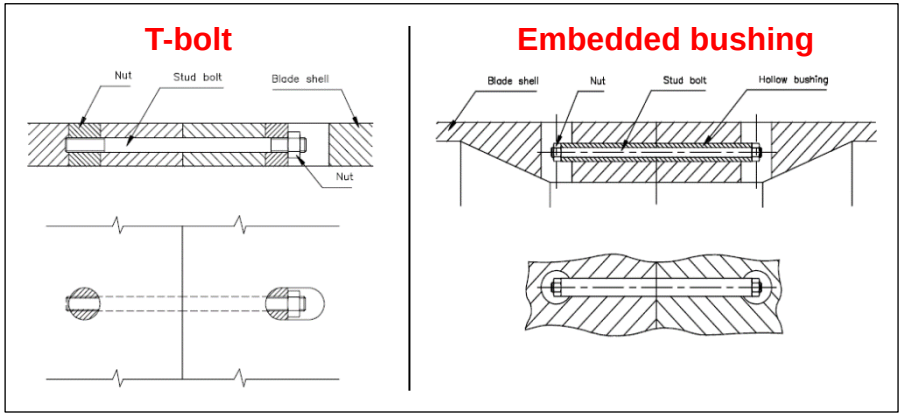
Concept studies

18 Concepts (bolting and bonding)

Detailed design including FE-modelling of 3 concepts: T-bolts, embedded bushings, connection tubes

Coupon tests of T-bolts and embedded bushings

- Weak point of embedded bushings: bonding of bushing and laminate
  >> T-bolts are more robust
- Embedded bushings need less space
- Load bearing capacity per unit width of T-bolts and embedded bushings is similar

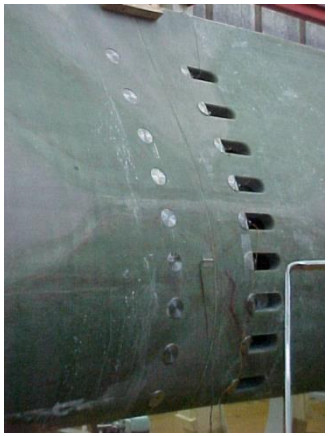


JOULE III (2)

Production and test of segmented **LM23.3** blade with T-bolt connection

- Produced in one piece, cut into segments afterwards
- NC-machine drilled holes
- Passed static und dynamic full-scale blade test, flapwise and edgewise
- Measurements showed higher than calculated load factors for the bolts at the trailing edge.
  Reason: 2mm gap between segments

Segmented LM23.3 with T-bolts



[2]

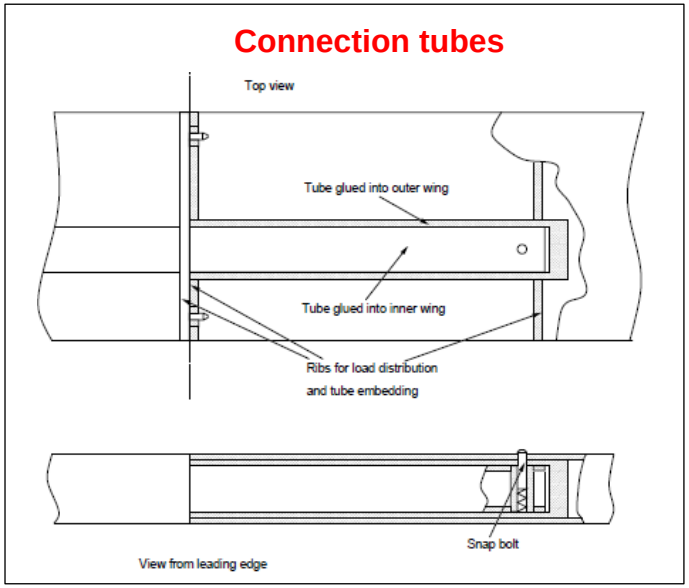
Economic evaluation of segmented LM23.3 with T-bolts vs. standard LM23.3

- Extrapolation of results to a 60m blade: *Overall costs for transportation, material and production of segmented rotor blade is 14% higher than of standard blade.*

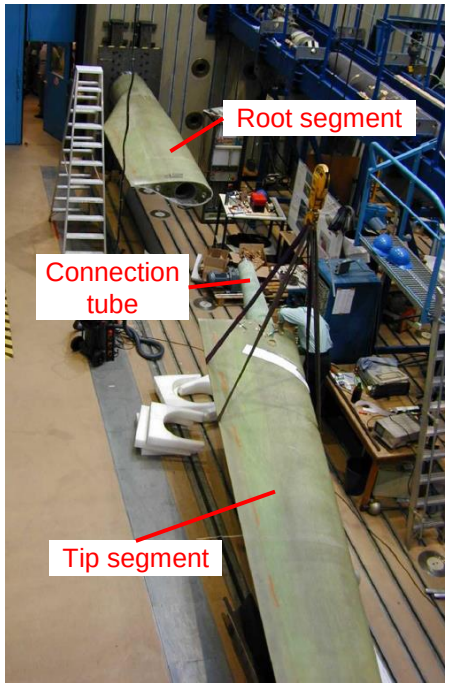
Result: T-bolts proofed technical suitability, but are economically inefficient

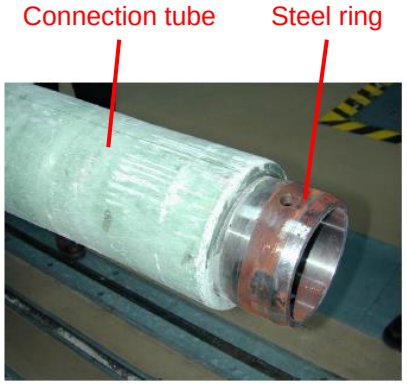
JOULE III (3)

Production and test of segmented **LM13.4 blade with connection tubes**



Segmented LM13.4 with connection tubes





[2]

- Passed static (flap + edge) und dynamic (flap) blade test
  >> minor damages because of bad fit

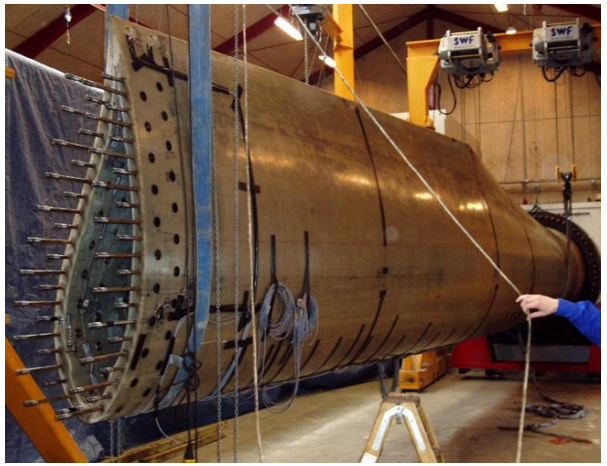
Result: Connection tubes proofed technical suitability

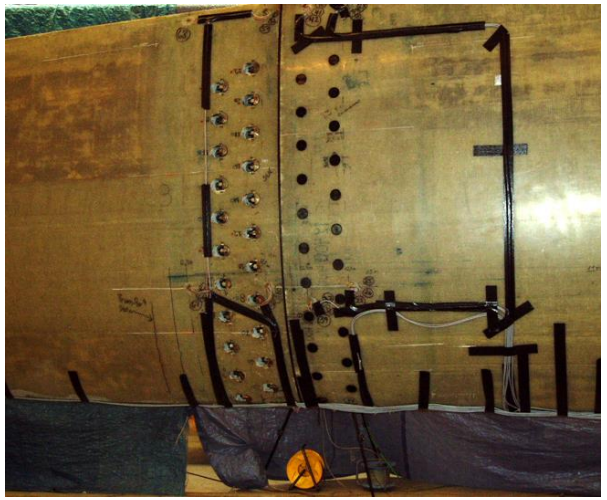
Megawind

Time span:	2001 – 2004
Blade length:	30m (12,7 + 17,3m)

Companies:	CRES, NTUA, UP, Risø DTU, …

- Design, production and test of segmented **30m-blade with double-row T-bolt connection**
- Production in one piece, then cutting and drilling
- Passed static blade test in flap- and edgewise direction
- Failed dynamic in flapwise direction: At 20% of design life, 9 of 44 bolts were broken
  - No obvious reason
  - Possible cause: irregularities in production





Result: Fatigue is a problem for T-bolts in big blades

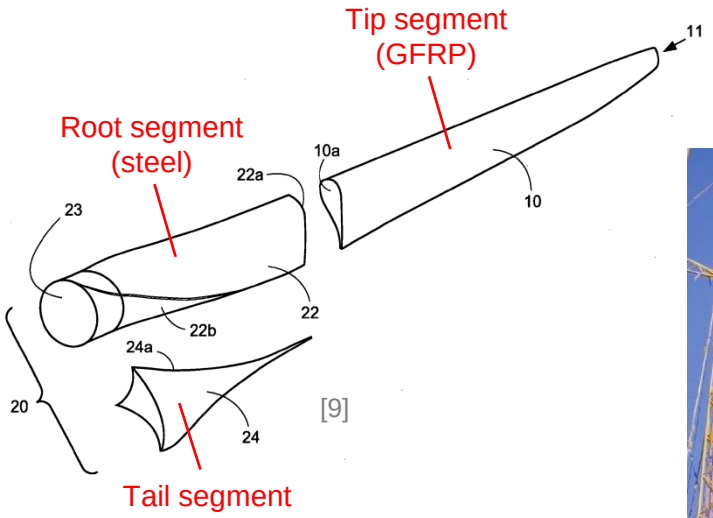
[3]

Enercon E-126

Time span: since 2007

Blade length: 59m (24 + 35m)

- Segmented blades with **T-bolt connection**
- **L-Flange** in root segment
- **T-Bolt** in tip segment

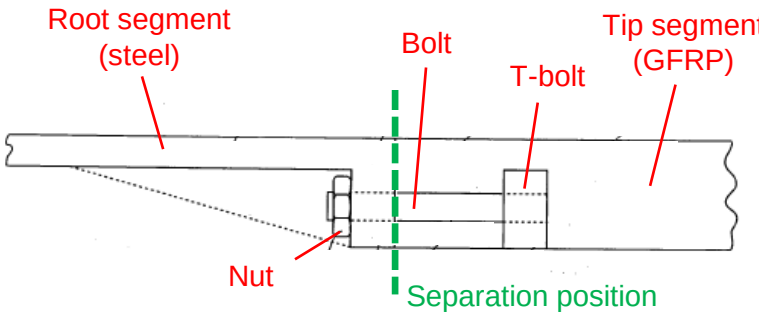


[9]

[4]

Technician inside the root segment

[8]



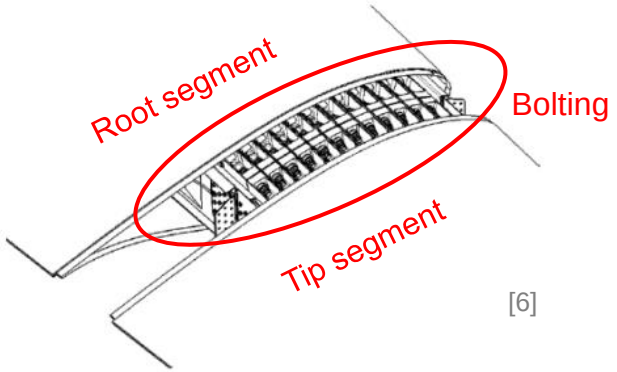
[9]

Gamesa Innoblade

Time span:	since 2006
Blade length:	62,5m (30,5 + 32m)
Companies:	Gamesa

Research program „UpWind“

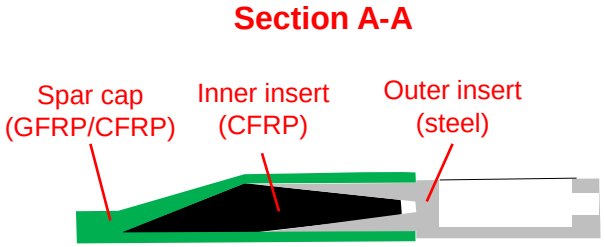
- Concept study (different bolting solutions)
- Detailed design of „**channel fittings**“



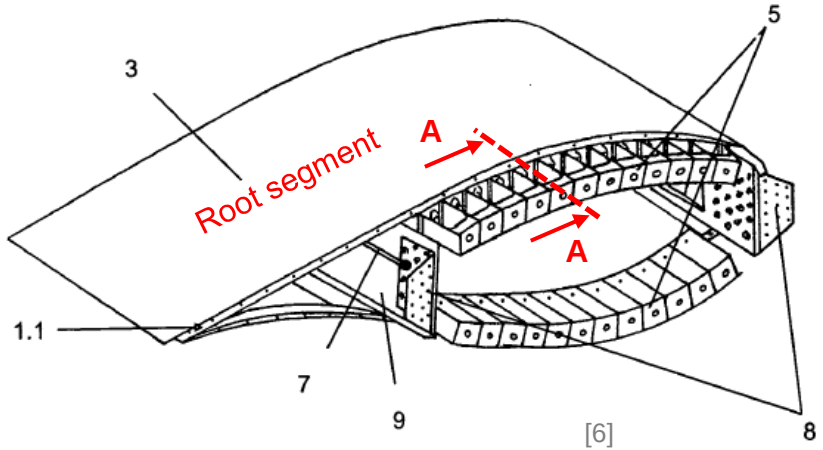
[6]

Gamesa Innoblade with „channel fittings“

- Erection of prototype in 2009
- Certification completed in 2011



[6]



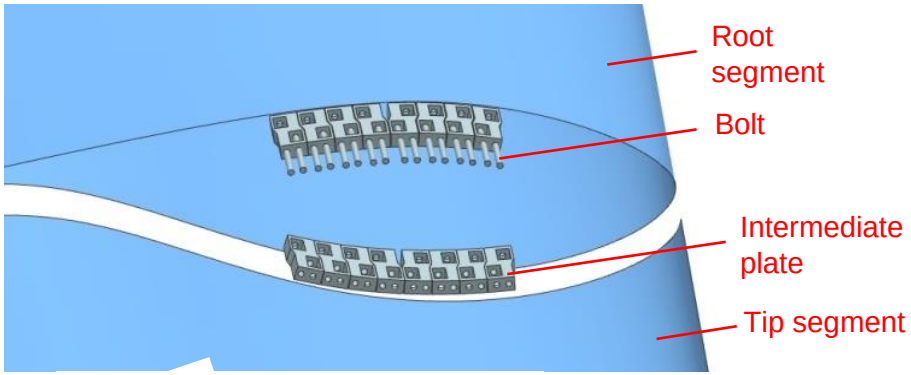
[6]

Indemodular

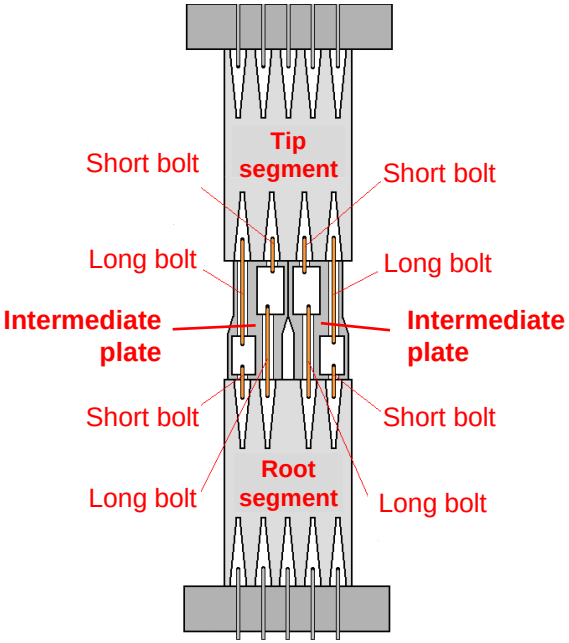
Time span: since 2010

Companies Indeol, CENER

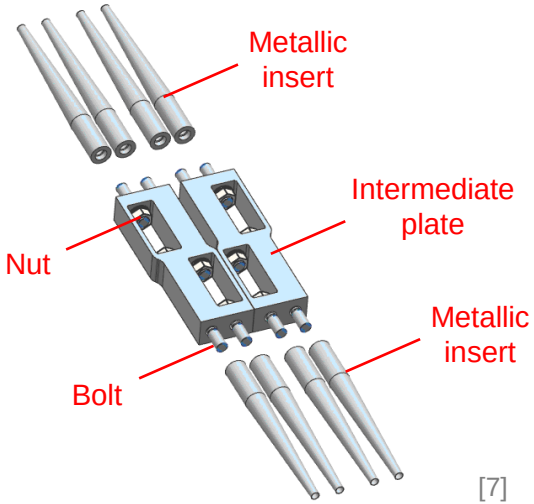
- Indemodular is a joining concept for bolting the spar caps
- Component tests



[7]



[7]



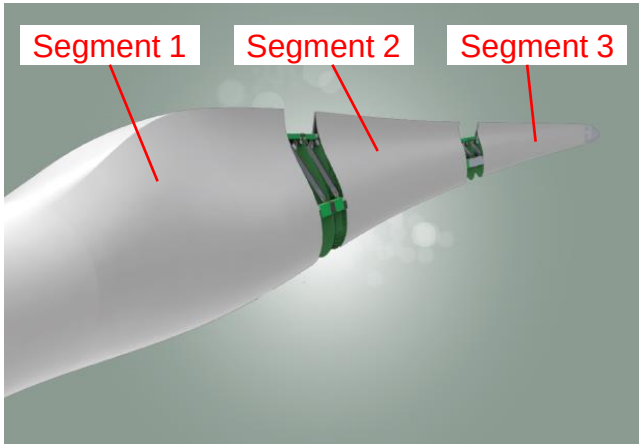
[7]

ModBlade

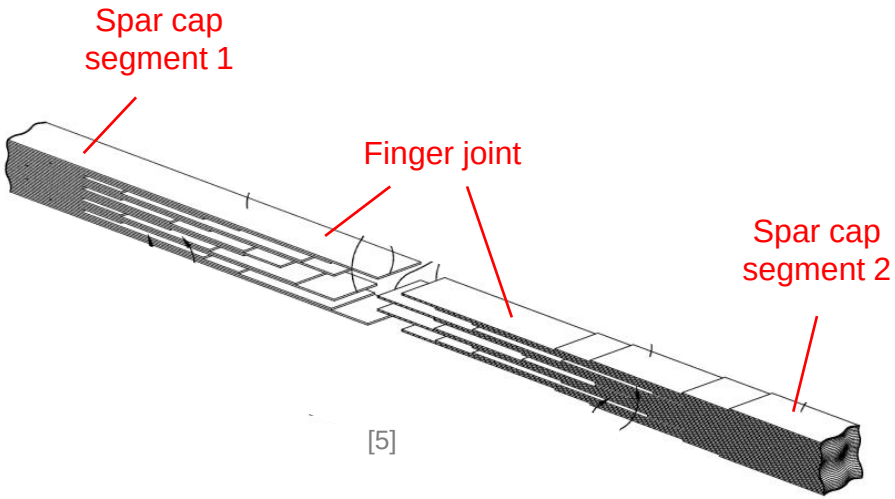
Time span:	2008 - 2013
Blade length	45m (3 segments)

Company	Modular Wind Energy

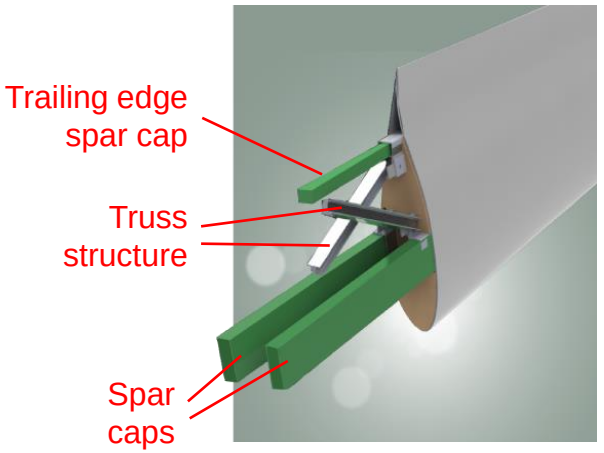
- Design, production and test of segmented 45m “ModBlade”
- Spar caps made of **pultruded planks (GFRP)**
- Joining of spar caps in a **bonded finger joint**
- Component and full scale blade tests



[10]



[5]



Summary

Bolted connections, in particular T-bolts, have been investigated the most

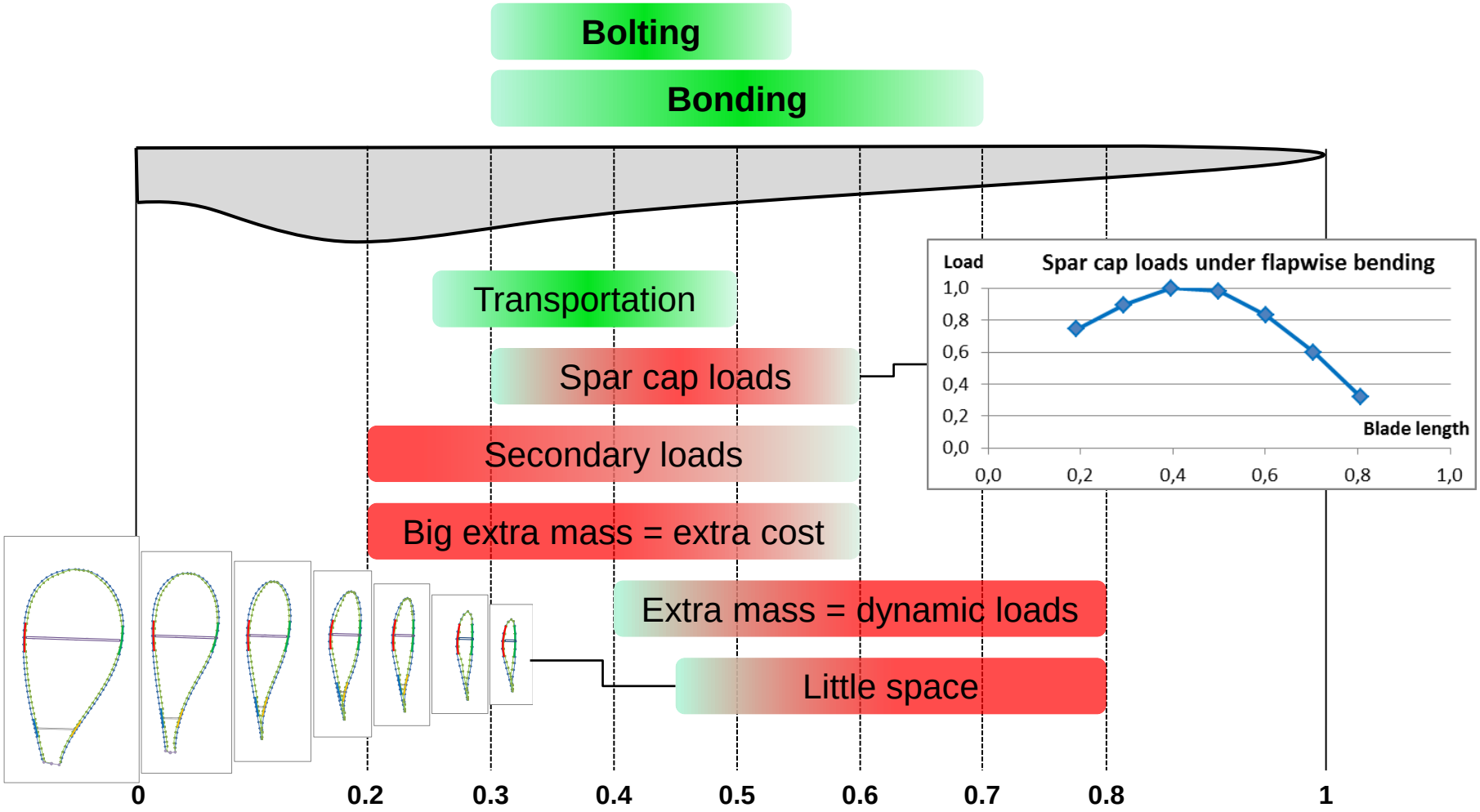
- Technical suitability
- Economic efficiency
  >> Big extra cost in materials and production

Bonded connections have been investigated only in the past few years

- Technical suitability not entirely proven
  >> Validated on-site joining process is still missing
- Economic efficiency is promising

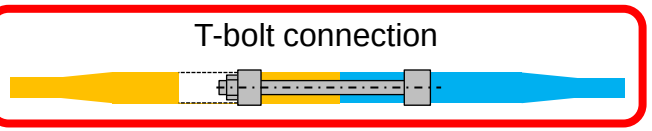
Result: Segmented blades are far away from serial production

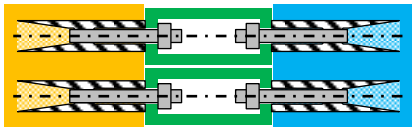
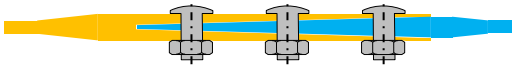
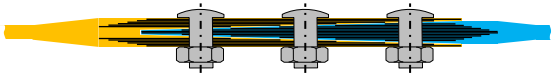
Where to cut the blade?



Considered concepts

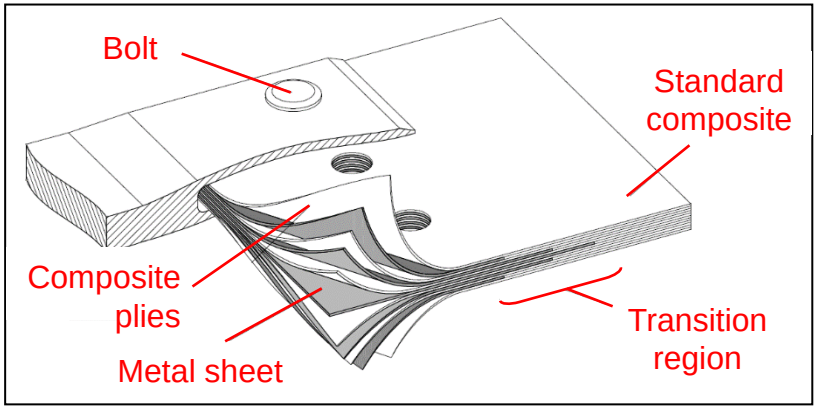
- Connection principle
  - Detachable
    - Bolting in longi-tudinal direction
      - T-bolts → T-bolt connection
      - Metallic inserts → Direct bolting of metallic inserts
      - Metallic inserts → Bolting of metallic inserts at an intermediate plate
    - Bolting in transversal direction
      - Form-fit → Bolting of GFRP
      - Form-fit → Bolting of fibre metal laminate
      - Force-fit
    - Bolting of pieces with a large overlap
      - Connection tubes
      - Bolting of shear web → Bolting of shear web
    - Welding of thermoplasts
  - Non-Detachable
    - Bonding of thermosets




Bolting of fibre metal laminate (FML)

- Local reinforcement of joint with FML
- 20 – 60 % metal volume fraction
- Metal sheet thickness: 0.1 to 1mm
- Material combinations: GFRP-steel, **CFRP-steel**, CFRP-titanium



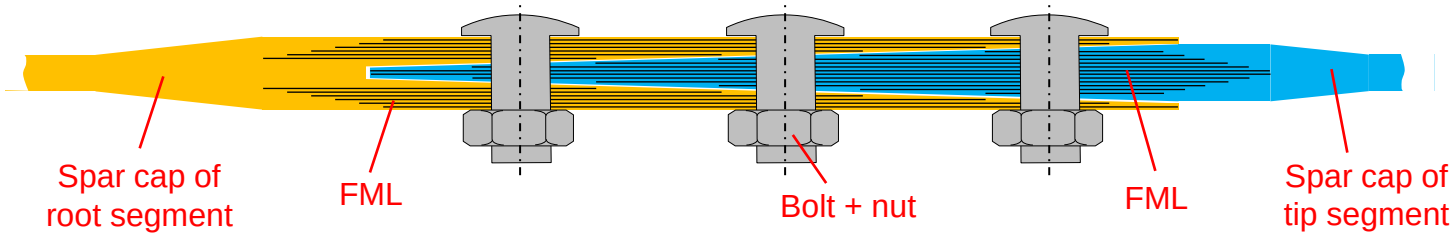
[12]

Pros

- Increased joint strength
- Little/no material thickening needed
- Low weight

Cons

- Costly materials (high-strength stainless steel)
- Special surface preparation for metal sheets
- Special tools required to make holes



Concept evaluation

Field	No.	Criteria
Structure	1	**Testability**
	2	**Weight**
	3	**Costs**
Production	4	**Integration in half shell construction**
	5	**Standard material and processes**
	6	**Production accuracy**
	7	**Quality assurance for production**
Assembly	8	**Simplicity and quickness**
	9	**Positioning accuracy**
	10	**Quality assurance for assembly**
Service	11	**Inspection during service life**
	12	**Repair during service life**
Aerodynamics	13	**Disturbance of aerodynamics**

Conclusion

- Segmented rotor blades are not yet capable of competing with conventional blades
- Bonding concepts still lack validated on-site joining process
- Bolting concepts need to be well designed to be competitive

Project outlook

- Detailed design of favoured concepts
- Optimisation of critical components
- Mechanical tests from coupon to full scale

MANY THANKS FOR YOUR ATTENTION.

Lutz Beyland

Nordex Energy GmbH / DLR

LBeyland@Nordex-online.com / Lutz.Beyland@DLR.de

German Aerospace Center (DLR), Institute of Composite Structures and Adaptive Systems

Lilienthalplatz 7, 38108 Braunschweig, Germany

Dr. Jochen Birkemeyer

Nordex Energy GmbH

JBirkemeyer@Nordex-online.com

Langenhorner Chaussee 600, 22419 Hamburg, Germany

References

[1] Debra-25: H. Böhnisch, H. Hald, C. Kensche, A. Kußmann, J. Molly, H. Seifert, *Entwicklung, Bau und Betrieb einer 30/100-kW-Windkraftanalage*, Interner Bericht der Deutschen Forschungs- und Versuchsanstalt für Luft- und Raumfahrt (DFLVR), Institut für Bauweisen- und Konstruktionsforschung, Stuttgart, 1988

[2] JOULE III: A. Dutton, C. Kildegaard, T. Dobbe, R. Bensoussan, C. Kensche, F. Hahn, D. van Delft, G. de Winkel, *Design, structural testing, and cost effectiveness of sectional wind turbine blades*, Final Report of Non-Nuclear Energy Programme JOULE III, 2000.

[3] Megawind: CRES, *30m split rotor blade (Megawind)*, http://www.cres.gr/megawind/split_rotor_blade.htm, accessed 11.09.2013.

[4] Enercon E-126: Enercon, http://www.erneuerbare-energien-niedersachsen.de/unternehmen/enercon.html, accessed 20.01.2014.

[5] Modular Wind Energy: C. Arendt, M. Baker, S. Vil-Hauer, M. Johnson, *Systems and Methods for Transporting and assembling segmented wind turbine blades*, patent specification WO 2010/135737 A1, 2010.

[6] Gamesa Innoblade: E. Sanz Pascual, I. de La Arocena Rua, S. Arroz Collado, *Blade insert*, patent specification EP2138716 A1, 2008.

[7] Indeol: E. Saenz, I. Nuin, R. Montejo, A. Ugarte, J. Sanz, *Design and Validation of a New Joint System for Sectional Blades*, European Wind Energy Conference 2013, Wien, 04.-07.02.2013.

[8] Juwi, http://www.juwi.de/mediathek.html, accessed 02.09.2013

[9] R. Rohden, *Rotorblatt für eine Windenergieanlage*, patent specification DE 102006022279 A1, 2006.

[10] Modular Wind Energy, *Company Description*, http://www.modwind.com/about-us/company-description/, accessed 05.09.2013.

[11] Nordex, blade data

[12] A. Fink, *Lokale Metall-Hybridisierung zur Effizienzsteigerung von Hochlastfügestellen in Faserverbundwerkstoffen*, Dissertation, Köln, 2009.